Development of potable town water supplies in saline aquifers using ASR

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Introduction

Aquifer storage and recovery (ASR), in the context of potable town water supplies, involves the injection of low salinity surface water into aquifers for storage, treatment and subsequent extraction. Two of the key objectives of ASR are to reduce the high infrastructure costs associated with mains water supply, thereby providing economically viable alternatives where traditional water supply is impractical, and use aquifers as water treatment media.

In the development of town water supplies in saline aquifers, the notion of both the sacrificial and potable lens (in unconfined aquifers), or bubble (in confined aquifers) is introduced (Fig. 1). The sacrificial lens provides the buffer and transition zone for the decay process to the native groundwater. The potable water supply lens is injected inside this initial lens.

The recovery efficiency (the proportion of injected water which can be recovered at suitable quality for the intended use), when highly saline aquifers (up to 30 000 mg/L) are used, may be very low. ASR systems in highly saline aquifers require a large water source, and are employed to overcome problems associated with toxic algae, and to provide water treatment. Concerns about the low recovery efficiency may be overruled by the economics of alternatives.

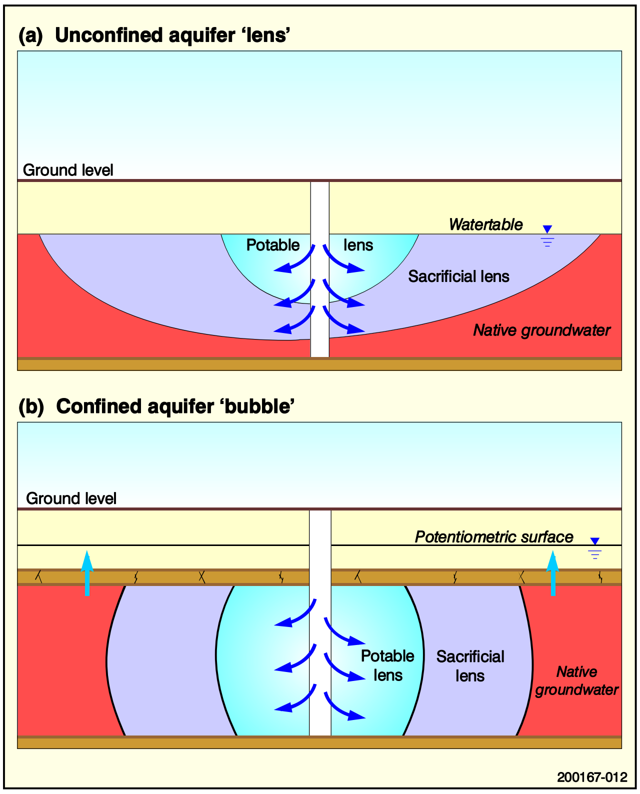

Fig. 1 Schematic diagram of the principle of ASR.

The recovery efficiency in saline aquifers (5000–10 000 mg/L) is expected to be much higher, and allows wider application of ASR systems at sites where there may only be small volumes of water available for injection.

ASR using confined aquifers is likely to result in a stable sacrificial bubble (in comparison to an unconfined aquifer), which will require less water to develop and maintain. Similarly, pumping from the potable bubble is likely to result in a much higher recovery efficiency when compared to pumping from a potable lens in an unconfined aquifer.

ASR using unconfined aquifers is complicated by the need to inject a large volume of water to form a stable sacrificial lens. In addition, upconing may be a problem when pumping (but may be overcome by multiple extraction points), the injected lens may move down regional hydraulic gradient and slowly disperse, and there is a greater risk of contamination.

This article includes a discussion of the operational ASR system at Clayton, which has been developed in an extremely hostile hydrogeological environment to supply potable water. Reference is made to the potential for using ASR to provide filtered town water supplies for other small towns along the lower Murray River in SA. The potential for *in situ* leaching (ISL) technology (now in use in SA for uranium mining) to mine salt from the volume of an aquifer to be used in an ASR system is also discussed. Further information on these subjects is contained in Gerges and Howles (1996), Gerges *et al.* (1996, 1998) and Heathgate Resources Pty Ltd (1998).

Clayton town water supply

Background

Clayton, a small town at the lower end of the Murray River system in SA (Fig. 2), draws its water supply from Lake Alexandrina which in summer months can suffer pollution from toxic algal blooms. An ASR system was envisaged in which lake water could be injected into an underlying aquifer during the winter months, when toxic algal counts are low, then pump this water for town use during any summer algal outbreak. Clayton requires 20 ML during the summer months, and has an annual demand of ~50 ML.

A 30 m deep injection well was completed in an unconfined, fractured, karstic Tertiary limestone aquifer early in 1995. A salinity of 30 000 mg/L and an airlift yield of 25 L/s

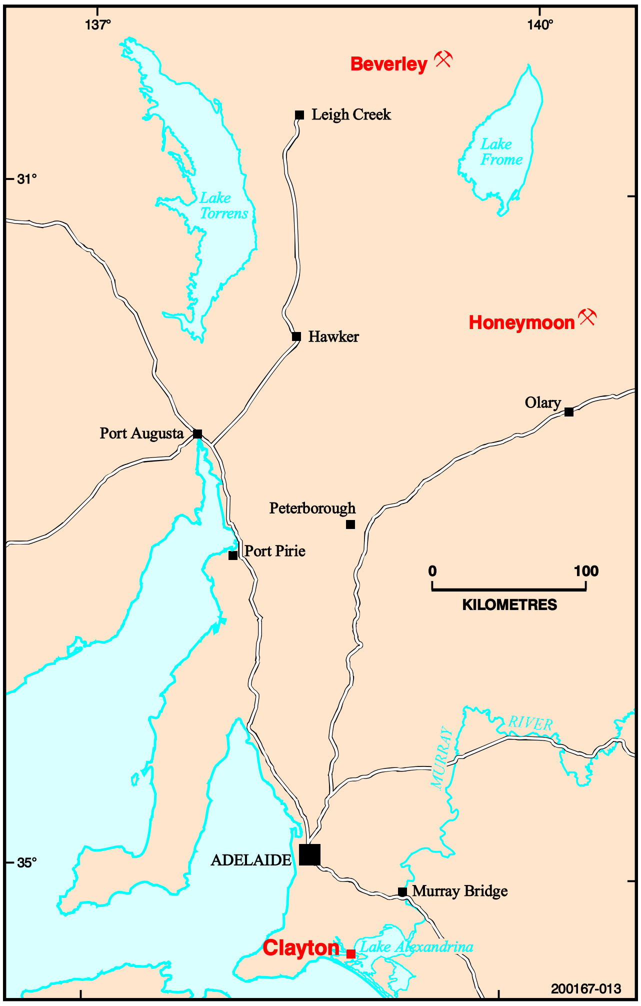

Fig. 2 Locality plan showing Clayton ASR site, Beverley and Honeymoon.

were recorded (40 L/s injection capacity at 4 m of injection head).

Trial injection of 10 ML, then a further 50 ML during 1995, followed by monitoring through to 1996, indicated the possibility of developing a potable water supply within the highly saline aquifer if a sufficiently large volume of water was injected. As a result, observation wells were drilled at radii of 5, 10, 25, 70 and 145 m to determine the extent and salinity profile of the lens.

Injection of 300 ML occurred during late 1996, which was terminated when the 25 m observation well contained 500 mg/L water throughout its profile (salinity at the 145 m well was 8000 mg/L). The water remained in residence for a period of 90 days, during which conductivity profiles indicated the decay of the lens. Profile data are given for selected dates (8/11/96, 8 days residence; 5/12/96, 35 days residence; 13/1/97, 74 days residence; Fig. 3).

In early 1997, a further 250 ML were injected, followed by 70 days of residence through to mid-1997. Following the end of this fourth injection cycle (total injection of 10 + 50 + 300 + 250 ML), a 20 m deep production well was drilled 10 m from the injection well, and a long-term recovery pumping test was conducted for 79 000 minutes (55 days) at 4 L/s, resulting in the recovery of 16 ML. Salinity data (following 8700 minutes; Fig. 4) indicate that the salinity

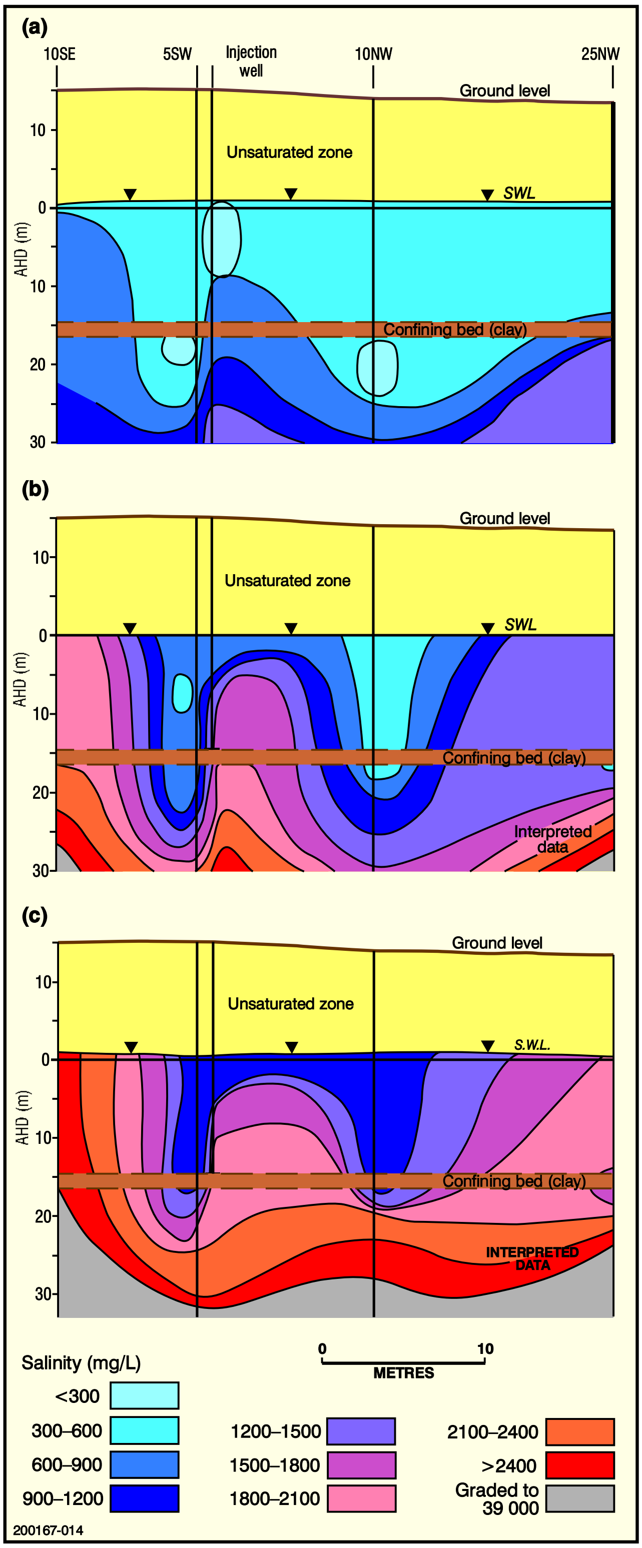

*Fig. 3 Salinity cross-section of the Clayton lens after injection of 300 ML of water. **(a)** on 8/11/96, after eight days residence, **(b)** on 5/12/96 after 35 days residence, **(c)** on 13/1/97 after 74 days residence.*

rose in a linear manner (from the initial 560 mg/L) until a time of 51 000 minutes (35 days), when 9.5 ML had been pumped and the salinity was 1100 mg/L (the final salinity was 1780 mg/L). Bacteriological sampling indicated that the water satisfied potable requirements with no further treatment. Pumping resulted in a significant decay in the lens.

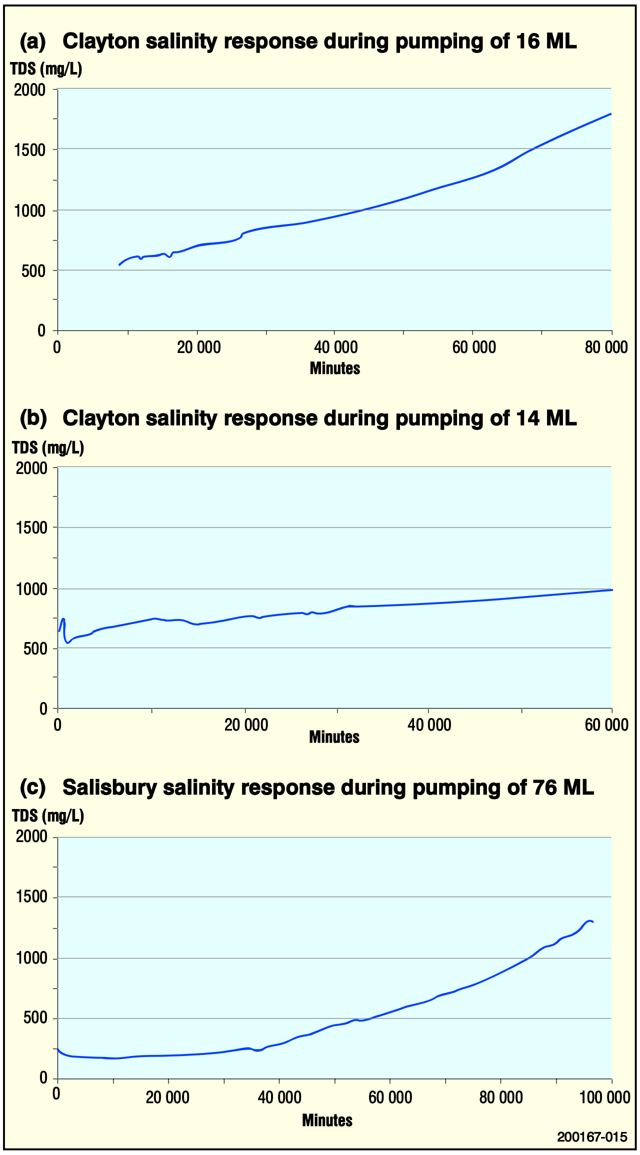

Fig. 4 Salinity responses at Clayton and Salisbury.

Trial operation (1997–98 and 1998–99 summers)

Due to insufficient understanding of the nature and stability of the lens, it was decided to operate the system through the 1997–98 summer with continuous injection and pumping until an algal outbreak occurred. Injection of 280 ML occurred between 3/10/97 and 17/1/98, when injection was terminated to complete the infrastructure; no algal problem occurred during the summer.

Pumping of 20 ML at a rate of 4 L/s for the town water supply (UV sterilised) occurred for a period of 69 days between 23/12/97 and 2/3/98. Between 21/1/98 and 2/3/98 (58 000 minutes, 40 days) following the end of injection in mid-January, 14 ML were pumped, commencing at 530 mg/L and ending at 1000 mg/L (Fig. 4).

Preparation for the 1998–99 summer involved the injection of 200 ML between 30/9/98 and 7/1/99; heavy pumping to the town commenced on 15/12/98. The system was stressed through the 1998–99 summer by relying on the injected lens for a period of 61 days (7/1/99–10/3/99), which provided the town water supply at a salinity below 1000 mg/L.

Operational issues

Controlling the lens

At present, a rule of thumb may be used to determine the readiness of the lens for long-term supply of water. If the 25 m observation well is flooded with water of a similar salinity to the injected water, the lens can be expected to support 'long-term' pumping. Outside of summer months, injection should occur on an 'as needs basis', sufficient to ensure that the lens is maintained in a reasonable state. Preparation for summer may require a significant volume of the order of 200–300 ML to be injected.

Ideally the lens needs to be calibrated so that the 'salinity state' the lens must be in to be able to undergo a residence period (of 1, 2, 3 months), and be capable of producing the required demand (of 10, 20, 30 ML) with a salinity <1000 mg/L, must be determined.

Clogging

Lake water has a suspended solids load of ~50 mg/L. The injected silt collects on the well and fracture walls and is slowly reducing the efficiency of the injection well, although this is not a problem at present. It is possible that reducing the permeability of the aquifer may have some advantage as it may increase the stability of the injected lens, resulting in the need for less injection.

Bio-geochemical problems have not been shown to be a problem at present.

Concluding comments

The Clayton ASR trial is an investigation of a novel and non-routine nature. The trial results indicate that a potable water supply can be developed in this extremely hostile hydrogeological environment. The system is very inefficient, as the recovery efficiency is only of the order of 5–10%, but this is offset by the economics of the alternatives.

Town water supply in lower salinity aquifers

Although ASR investigations have been conducted in a highly saline (up to 30 000 mg/L) aquifer in SA, no work has been undertaken using saline (5000–10 000 mg/L) aquifers for developing potable water supplies. However, the irrigation water supply system in Salisbury (a northern suburb of Adelaide), developed in a marginally saline aquifer, gives some indication of the response that may be expected in saline low permeability confined aquifers. At this site, a 160 m deep well was completed in a confined silty sandy limestone with a salinity of 1800 mg/L, adjacent to a wetland that provides low salinity, low turbidity water for injection.

Due to low permeability of the aquifer, this system operates at an injection rate of 7–10 L/s, with an injection head of 70 m. The well can be pumped at a rate of 10 L/s. Interestingly, during trial injection in 1996, the well became more efficient with time, suggesting that clogging mechanisms were dominated by dissolution of the limestone.

Preliminary injection of 75 ML was completed during 1996, followed by a 97-day residence period, then pumping of the injected volume. The salinity response during this first cycle of pumping over 96 000 minutes (67 days) indicated that 40% was recovered with a salinity similar to that of the injected water (250 mg/L), and 90% was recovered with a salinity <1000 mg/L (Fig. 4). These data provide some indication of the response which may be expected from an aquifer with similar hydraulic characteristics, but higher salinity.

Lower Murray River town water supplies

Background

SA Water is currently interested in the potential of using ASR to provide filtered water supplies to small towns on the lower Murray River at less expense than the cost of installing filtration plants. Toxic algae are not considered to be a major problem for potable water supplies along the river. The main reasons for this proposal are the removal of bacteria and enteric protozoa, and reduction in turbidity which will improve the effectiveness of disinfection. Such a project is technically challenging, and would allow further development of the knowledge base commenced at Clayton.

Technical issues

The following technical issues will require definition by drilling and testing of exploration wells at each site:

- aquifer definition — depth, thickness
- depth to water, yield, flow direction, salinity distribution
- well and aquifer hydraulics.

The following points (several of which are discussed in more detail below) are of particular concern for ASR:

- volumes of water required for injection
- number of wells, configuration and construction (production zone), efficiency and available injection head
- up-coning of saline water when pumping
- effectiveness of aquifer filtration
- well clogging
- bio-geochemical reactions and contamination
- induced movement of saline groundwater towards the river
- operational recommendations.

Volumes of water required for injection

The volume of water required at each site for developing a stable sacrificial lens or bubble with a potable core, and the volume required annually to add to the sacrificial lens and develop the potable core, is unknown. However, assuming the aquifer chosen at each site is not karstic, it may be possible to develop a stable lens or bubble with much smaller multiples of the actual annual demand than were needed at Clayton, even though the demand is greater.

Effectiveness of aquifer filtration

Turbidity values as low as 1 NTU and bacteriologically free water (compared to 140 coliforms/100 mL of lake water) were achieved at Clayton.

Well clogging

Of particular concern to ASR is the potential for clogging with the turbid Murray River water (as high as 450 NTU), which may need to be pre-filtered using irrigation style filters to reduce the load prior to injection.

Implementation

A similar system to that developed at Clayton would need to be implemented, involving injection, production and observation wells. Poor hydraulic characteristics of injection wells may be improved by acidisation, which has been successfully trialed in carbonate aquifers in the Northern Adelaide Plains.

Assuming a potable lens requirement of 100 ML, an aquifer thickness of 20 m, porosity of 15%, and cylindrical spreading of the water, the edge of the potable lens would occur at a radius of 103 m from the injection well. The edge of the sacrificial (assuming five times the potable lens volume) and potable lens, a total of 600 ML, would be at a radius of 252 m. Observation wells extending beyond the edge of the sacrificial lens are required.

ISL technology applied to ASR

ISL technology and uranium mining in SA

The recent emergence of ISL technology in SA, currently being used to mine uranium at the Beverley deposit (and probably Honeymoon and other sites in the Frome Embayment; Fig. 2), may have application in the development of potable water supplies in saline aquifers.

At Beverley, ISL mining involves the dissolution of uranium contained within a confined palaeochannel, by the drilling of multiple systems of wells, and the cycling of chemically modified groundwater. As a result, the dissolved uranium can be precipitated at a chemical plant on the surface. This process avoids the need for underground mine workings, or removal of overburden in open-cut mining, and results in low-grade deposits becoming economic.

The basic element of the well field is the five-spot pattern (Fig. 5), which is composed of four injection wells surrounding a production well in close proximity (~50 m apart). Numerous patterns may be in operation at the same time. The injection rate is always slightly less than the pumping rate, thus preventing the potential of excursions of contaminated water from the mining zone. The small amount of waste which is produced in the process is reinjected back to the highly saline aquifer which is also heavily laden with radionuclides. At Beverley, the palaeochannel has been demonstrated to be sealed vertically and laterally from other aquifers.

Following completion of mining, wells are decommissioned, the chemical plant is removed, and the surface rehabilitated to the pre-mining state or better.

Application of ISL technology to town water supplies

There may be potential for the use of ISL technology in development of potable water supplies in saline aquifer. ISL may be used to mine salt from the volume of the aquifer to be occupied by the sacrificial lens or bubble. This rapid exchange process is likely to be considerably more effective (in terms of time and end result) than the current method of flushing the aquifer by injection and displacement of the native groundwater, and allows for ongoing manipulation of the volume of the aquifer occupied by the sacrificial lens or bubble. Once salt mining is complete (which may involve reduction of the salinity to a moderate level of perhaps 2000–3000 mg/L), injection of the potable lens (using a

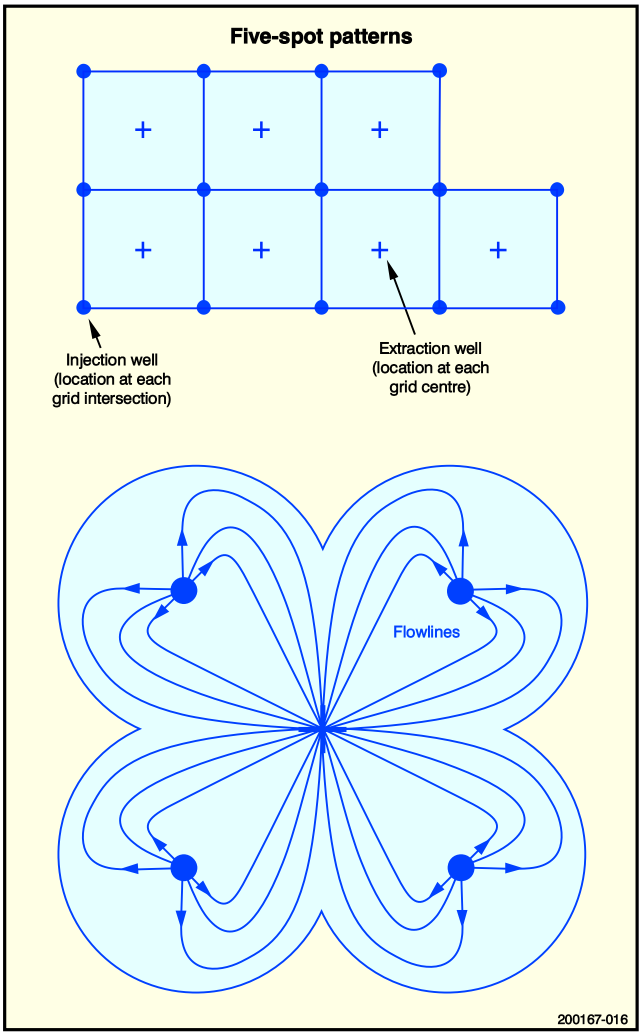

Fig. 5 Diagrammatic representation of a five-spot ISL mining pattern.

central pattern) into the modified hydrogeological environment could then be achieved with ease.

Such a mining operation would operate with a greater injection rate than pumping rate (the reverse of uranium mining) to ensure a loss to the aquifer of low salinity water. The waste stream of highly saline water may be reinjected into the same aquifer at some distance from the ASR site, or possibly a different aquifer.

Such a proposal could only apply in situations where there are large volumes of low salinity water available for the mining process (as along the Murray River), and would only be likely to be applied to town water supplies, as the additional cost of drilling the well field is unlikely to be justified for an irrigation system.

Conclusions

ASR has the potential to provide town water supplies in highly saline aquifers (up to 30 000 mg/L), where large volumes of water are available for injection, to provide potable water in situations where toxic algae may be a problem, and where water treatment is required. Saline aquifers (5000–10 000 mg/L) may have wider application for potable water storage and recovery.

The two extreme examples in carbonate aquifers (cited above) indicate the difference in injecting and recovering water from a highly saline unconfined high-permeability aquifer, and from a saline low-permeability confined aquifer.

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